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SOME UNIQUE APPLICATIONS FOR TETHERED BALLOON SYSTEMS.(U)

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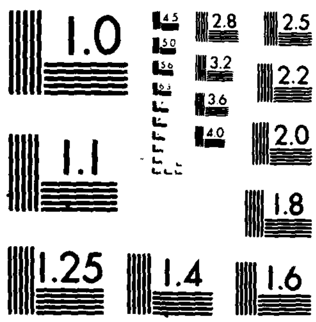

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SOME UNIQUE APPLICATIONS FOR TETHERED BALLOON SYSTEMS

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Abstract

Properly designed tethered balloon systems are remarkably versatile test platforms. They can be erected quickly, to great heights, and provide unobstructed viewing. For electromagnetic measurements, tethered systems can be made acceptably non-metallic; for acoustical studies they are quiet. This paper describes several systems designed and operated by the Air Force Geophysics Laboratory: a dual array to erect and recover a 1000-ft square, flexible net with carbon fiber collectors; a single tether, supporting sensors along its length for boundary layer measurements; a tritethered emergency substitute for a LORAN antenna; and tritethers for a weapons evaluation system and for tests of the Surveyor moon lander.

Introduction

By far the greater number of lighter than air systems developed and flown by the Aerospace Instrumentation Division, Air Force Geophysics Laboratory, are very large, heavily instrumented polyethylene balloons for experiments at altitudes up to 170,000 feet. In a typical year, however, there comes at least one urgent request for consultation and field support for an unusual experimental program which requires us to respond very quickly with an integrated tethered balloon payload system, and also with -- of critical importance -- a well rehearsed, detailed operational plan which will make the system work. Table 1 describes the tethered balloons currently available at the Laboratory's permanent balloon test facility, AFGL Detachment 1, Holloman Air Force Base, New Mexico.

In many instances, a tethered balloon is the only feasible solution to the experimenter's test problem. Compared to a conventional tower, a tethered balloon:

- provides virtually obstacle free visability,
- can be erected to much greater heights,
- can be erected and dismantled quickly, even in remote locations,
- can ascend and descend at controlled speeds.

The obvious question, is whether the system will be sufficiently rigid for the proposed application. In practice, this potential drawback can be overcome to a surprising degree by careful planning. A payload can be positioned above the precisely defined, very small target area by using a multi-tethered balloon; the practicable altitude is then considerably less than is possible using a simpler cable arrangement. Most of our multitethered systems have been tritethers. Although a four-tether system ensures better rigidity in winds from all directions, this precaution is usually not necessary, and it requires a larger balloon

Table 1 Tethered Balloons in AFGL Inventory

Aerodynamically Shaped

Volume ft^3	Design	Diameter ft	Length ft	Payload lb	Max. Altitude ft AGL
4,300		15.75	40	35	1,200
6,000	Fam II	16.34	50.36	51.3	2,500
6,000	BJ	18	48	38	2,500
19,000	Fam II	24	73	230	6,000
30,000		29	79	118	10,000
45,000	Fam II	31.9	98.5	360	10,000
45,000	BJ	33.5	90	380	10,000
70,000		39	106.6	230	15,000
100,000		43	120	790	15,000

Natural Shaped

Volume ft^3	Diameter ft	Height ft	Payload ft	Max. Altitude ft AGL
5,573	24	24	60	3,000
20,000	33	39	260	6,000
28,000	40	49	260	10,000

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to lift and tension the extra cable, with all of the consequent complexity of a larger system -- more crew, more helium and more time to erect and to dismantle the balloon.

The flying characteristics of the modern computer-designed balloons are so far superior to those of the older, barrage types, we are now using the very stable Family II designs, on a single cable, to great advantage. We have also been very successful in erecting and supporting large, two-dimensional, flexible targets using just a pair of aerodynamically shaped balloons - one at each upper corner.

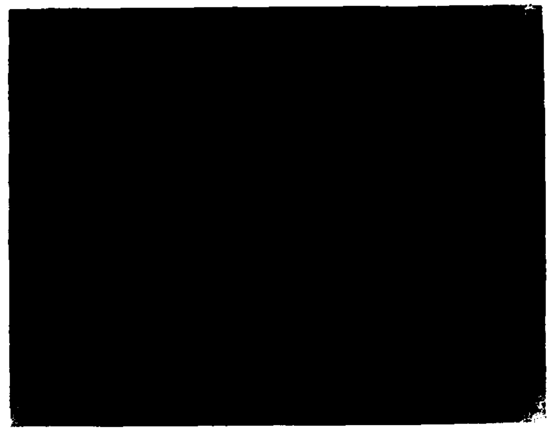

Figure 2. One of the balloons at altitude.

The Carbon Fiber Burn Risk Experiments

We used a pair of 45,000 cu ft BJ-type balloons for tests to evaluate the national risk associated with a crash and fire from aircraft containing parts fabricated from carbon fiber composite materials.* The balloons were needed to erect and lower a flexible network of Kevlar cables 1000 feet high by 1000 feet wide, called the "Jacob's Ladder", located 500 feet directly downwind from a burning pool of the carbon fiber composite aircraft components and JP-4 fuel, Figure 1. Five hundred-odd, viewgraph-sized collectors for measuring the burning residue were attached to the net. It was mandatory that the very unwieldy, one million sq ft flexible structure should be raised from the horizontal, held aloft vertically under tension during the test period, and then lowered back to the horizontal, keeping the net sufficiently taut at all times to prevent any accidental contact among the uncovered sticky plates and other samplers. Figure 2 is an upward view showing one balloon and part of the net, in place.

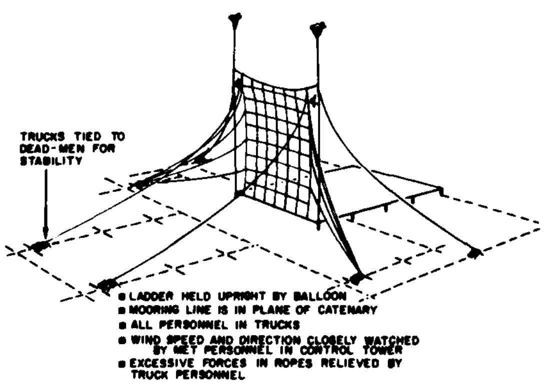

Figure 1. Jacob's Ladder

With less than four months lead time, we devised a minutely detailed operational plan whereby a contractor constructed a vast rope "worktable" supported on 7-ft high posts, Figure 3; personnel standing beneath the rope table formed the Jacob's Ladder by interconnecting the Kevlar cables, using the rope table to support the Ladder; then they fastened the samplers to the Ladder. The base of the Ladder was secured to ground by attaching the individual cables to ground anchors. Along the top of the Ladder the vertical cables were fastened along a catenary, and each terminus of the catenary was attached to the load line of a balloon. In a carefully orchestrated procedure, the interconnected balloons were slowly winched up, Figure 4; then, with the net in position, Figure 5, the pool of fuel and carbon fiber parts was ignited, Figure 6.

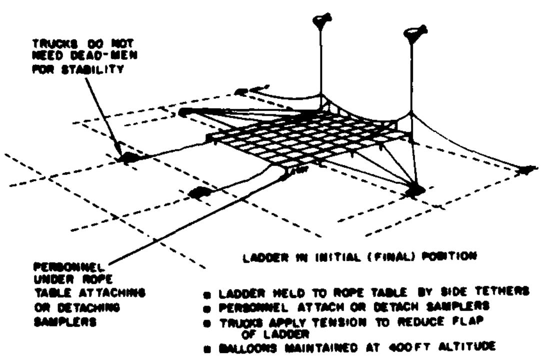

Figure 3. Ladder on rope table.

After the burn, the Ladder was lowered onto the rope table, the samplers detached for analysis of the residue, and the balloons deflated. Five of these operations were run with complete success at the U. S. Army Dugway Proving Ground, Utah. As a result, NASA determined by measurement that the carbon residue from a burning aircraft is appreciably less than predicted from modeling and tunnel

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* The DOD was one of several government agencies participating in this program. It was managed by NASA for the Office of Science and Technology Policy, Executive Office of the President.

testing. Consequently, the cost-effective, lightweight carbon composite material can now be used extensively for civilian and military aircraft.[1, 2] Moreover, this new capability for large area sampling at extended heights is now available for a variety of aerosol sampling and dispersion studies.

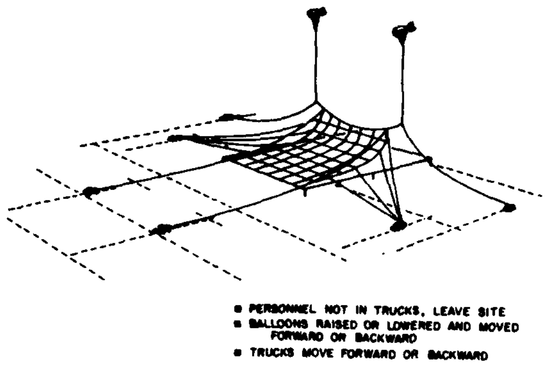

Figure 4. Ladder being raised (or lowered).

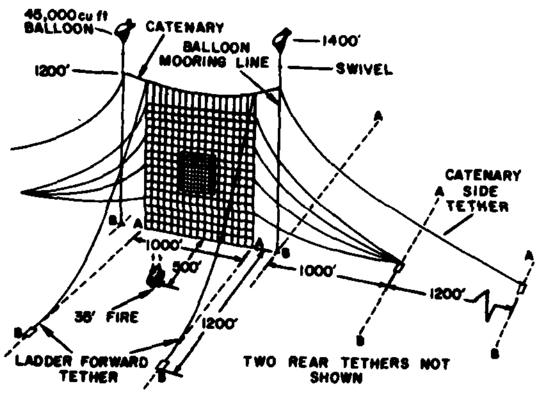

Figure 5. Schematic of ladder lines.

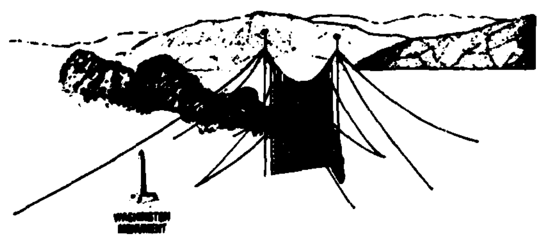

Figure 6. Schematic of the sampling

The Minnesota Boundary Layer Experiment

Until an international team* of micrometeorologists elected to fasten sensor packages at intervals along the cable of a balloon tethered at 6000 feet, virtually all studies of the earth's boundary layer had been limited to the surface layer, below 150 ft altitude. Their objective was to determine the vertical flux of momentum and heat in the lower atmosphere by measuring the covariance between horizontal and vertical wind component fluctuations, and between vertical wind and temperature fluctuations. Before committing their resources to a major field operation on the plains of Minnesota, these reserachers ran a series of 50 comparison tests - balloon versus tower-mounted sensors - so that they could examine the effects of the balloon motions on the response characteristics of their cable-mounted sensors.

These experiments were made using a 1200-ft tower at Eglin Air Force Base, Fla. The balloon was flown variously at 1200, 2000, 3000 and 4000 ft altitude so that the effect of the separation distance between sensors and balloon could also be determined. Data were not wanted during meteorological conditions when there were strong and abruptly changing vertical motions. Consequently the balloon motion was always nearly horizontal. The data analysis clearly showed that the average values of the vertical fluxes were not at all affected by this balloon movement, or even by the distance between the balloon and sensors on the cable.[3] Although the individual values of windspeed were, of course, affected by balloon motion, this problem could be practically eliminated by maintaining a separation distance of 2000 feet or more between the sensors and the balloon.

The salient finding for others planning tethered-balloon experiments is that the phenomenon under investigation took place at scales of motion quite large compared to those of the balloon in use. With this sure knowledge of the system's performance, the research team could conduct the program and publish the results with a high degree of confidence.[4] The Minnesota Boundary Layer Experiment was performed in the Red River Valley where the terrain closely approximates a uniformly flat plane for tens of miles, Figure 7. Balloon Volume was 45,000 cubic feet.

The LORAN Emergency Antenna

The Long Range Navigation System, LORAN, is used by ships and aircraft around the world. A LORAN "chain" consists of three, 400-ft towers, one primary and two slave stations located about 400 miles apart. All three towers are needed to keep the chain operational. If one or more were damaged the network would be "down" for weeks until a new tower could be erected. At the request of the USAF Tactical LORAN Special Projects Office we developed a tethered balloon-supported, long wire antenna to demonstrate that such a system could temporarily replace a downed tower antenna.

*This was a joint program by the USAF Cambridge Research Laboratories (now the Air Force Geophysics Laboratory) and the Meteorological Research Unit, RAF, Cardington, England.

Figure 7. Minnesota Boundary Layer Experiment

It must be as uncomplicated as possible so that it could be transported by air and rapidly erected by a few people who lacked specialized training in balloon deployment. The emergency system is illustrated in Figure 8.

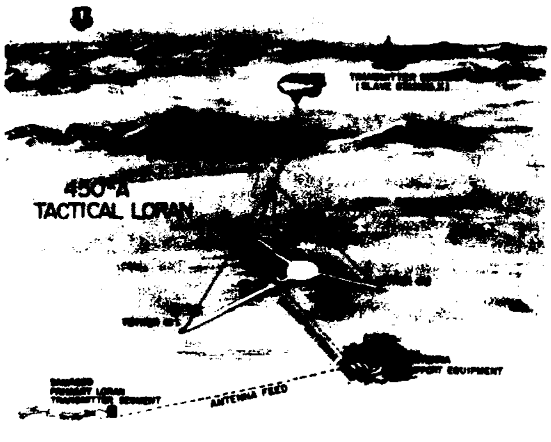

Figure 8. Balloon-supported LCRAN antenna

To an even greater degree than is usual in our tethered programs, the balloon and its 500-ft long emergency antenna payload are an integrated design. The top of the antenna center element is supported at the apex of a tritethered Kevlar cable pyramid. The 45,000 cu ft balloon is attached to the pyramid apex through a 500-ft long, single flying cable. This arrangement provides good stability of the pyramid while allowing the balloon freedom for some wander.[5, 6] The antenna has an aluminum center element and three top loaders. The top loaders are formed by overbraiding two layers of aluminum wire down along a distance of 700 feet on the 788-foot Kevlar tritether cables.

From a computerized analysis of this antenna configuration[7] it was apparent that very high corona losses could occur, making the antenna inoperative, and degrading or even destroying the Kevlar cables. Consequently, every possible precaution in the design and construction was taken to minimize such losses. Special hardware was devised for attaching the antenna to the tritether apex; for the feedpoint at the lower end of the vertical element of the antenna, and for lightning protection.[7] Because our standard instrumentation for balloon control and safety would be jammed by the antenna radiation, the usual relay- and diode-controls were replaced by a "smart" valve with an aneroid control which locks the valve open in the event the balloon should break away, and a differential pressure sensor to control balloon overpressure.[6, 7] This emergency antenna system was erected and operated at the LORAN site in Anniston, Alabama during June, 1978.[6]

Weapons Evaluation Operations

Evaluation of sensor performance for weapons development has proved to be a particularly useful application for tethered balloon systems. HOMINE (homing mine), for example, was an acoustic homing device which had to be tested in a very low noise environment -- a helicopter or other powered aircraft was entirely unsuitable as a carrier vehicle. Instead, the HOMINE under test was suspended, Figure 9, and dropped from beneath a 38-ft diameter, spherical, tritethered balloon which was sited precisely in relation to a defined target area on the ground, Figure 10. For some of the tests, the moving target was an M-48 tank, Figure 11.

Figure 9. HOMINE launch on tritethered balloon.

Figure 10. The HOMINE experiment.

Figure 11. Tank target for HOMINE.

Shock Wave Tests

For the Naval Surface Weapons Center and the Los Alamos Scientific Laboratory, a 38-ft diameter natural-shaped balloon was erected 800 feet above Ancho Canyon, Los Alamos, New Mexico, Figure 12. It carried frame structures several hundred feet tall, for tests to observe the effects of air shock waves on such structures.

Figure 12. View from above into Ancho Canyon.

SURVEYOR Moon Lander

Several of our more exotic programs using free balloons were performance tests of parachutes and and vehicles intended for planetary landings. Usually they were released into a very low density region of the earth's atmosphere where some critical properties of their space environment can be simulated. To perfect the controlled descent and soft landing technique for the SURVEYOR Moon Lander, however, we earlier had provided a drop platform just 1500 feet high, having positioning capability to ensure impact of the Lander within 50 feet of a fixed point on the ground. SURVEYOR had a retromotor to reduce its speed from about 6000 mph to 240 mph, and three radar-controlled vernier engines to slow it down while changing its orientation as required for the three-point, soft landing.

For the extensive, balloon-borne testing, a 66-ft diameter, spherical balloon was tritethered, using winch-equipped trucks to maneuver the tri-tether apex precisely over the designated ground zero. The SURVEYOR vehicle was suspended beneath an extended parachute cluster which was attached at the apex to the balloon end fitting. Upon release, the vehicle was stabilized by a drogue chute until it reached 80 fps. Then the parachute was separated and the Lander descended under closed loop flight control and the verniers, to touch down at about 20 fps. Using the easily erected balloon system with the open viewing afforded by the lack of a tower structure, it was possible to observe each stage of the programmed descent trajectory, and to repeat the experiment as often as required without undue delay.

Tethered Balloon Pointing Control

In September, 1981, we made the first field test of a pointing control* which is being developed for use on our tethered balloons. It was used to point a retroreflector at a fixed target on the ground for an optical experiment. The pointing

*This device is being designed and developed by Dr. Alvin H. Howell at Tufts University under USAF Contract F19628-80-C-0060.

control, telemetry package and balloon safety and control instrumentation were flown at AFGL Detachment 1 at Holloman AFB, New Mexico, on a 45,000 cu ft aerodynamically-shaped balloon. The optical data and pointing control performance data were recorded with the balloon flying at various altitudes up to 1800 feet AGL, and also during ascent and descent under winch control. The exact performance measurements are not yet available. The ability of the pointing control to acquire and remain on target, and to respond to commands to change elevation and azimuth, however, was clearly demonstrated.

The addition of this new capability to our tethered balloon instrumentation is expected to make our tethered balloon systems useful for many applications which have hitherto been precluded by the natural motions of the balloon and tether line.

Conclusions

This sampling of the Air Force Geophysics Laboratory tethered balloon programs is intended to demonstrate the great variety of scientific and military applications for these ostensibly simple vehicles. Above all, we want to emphasize the fact that the experiment and the balloon must be treated as an integrated system. One does not decide to hang an experimental payload on a sufficiently large aerostat and hope for the best; neither should one assume, without serious consultation with experienced balloon engineers, that a proposed application is impossible. The one key element in the success of each of these unusual applications described above was meticulous planning, with joint participation by the experimenters and balloon experts.

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